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Aerospace Composite Structure Impact Test

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por Licenciados "Pré-Bolonha"

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Summary

After finishing my mechanical engineering degree in 2000, and after a brief experience in the automation/pneumatics field, I started working in the aerospace industry as a Stress Engineer.

I had the chance to join an outstanding company, Ogma (Alverca-Portugal), which gave me the opportunity to learn and master my stress analysis knowledge and expertise. I was sent to Airbus (Madrid-Spain) for a 6 month specific training in stress analysis in metallic and composite aeronautic structures, strength check, fatigue analysis, FEM, and different types of tools and structure validation techniques with several Airbus senior engineers.

According to the collaboration agreement between Airbus and OGMA, this training was then complemented with 6 months working at Airbus facilities, integrated in their engineering team. My responsibilities were: Airbus A400M Elevator conceptual design phase activities, composite parts sizing, structural requirements, structural analysis and FEM.

After the cancellation of the program I was working on, and realizing the lack of structural analysis and aircraft structures design projects, I decided to leave Portugal and continue my learning process, gaining experience, through the participation in challenging and state of the art projects.

In 2002 I left to Spain to work at Aries-Complex (Madrid-Spain) as a stress engineer in the Falcon 7X Elevator and Airbus A380 Vertical Tail Plane projects. After these projects I worked at ITD (Madrid-Spain) in the Airbus A380 muffler project.

In 2004 I had the opportunity to move to Belgium and work at Sonaca (Brussels- Belgium). I was responsible for the Airbus A400M Main Landing Gear Doors, Embraer 170 Frames weight reduction, Airbus A380 Nose Upper Shell. Along with my stress analysis duties, developing composite parts and performing structural analysis, I also participated in the structural repair manual (SRM) elaboration, which introduced me into the world of composite structure repairs.

After nearly 2 years in Belgium I returned to Spain to work at Rucker Aerospace (Barcelona-Spain) and Aernnova (Vitoria-Spain). I participated in programs such as the Airbus A380 freighter, Sikorsky H92 helicopter fuselage, Hawker-Beechcraft Red Wing (developing 3 different wingbox configurations for an aircraft family), and Boeing 747-8 Intercontinental Fuselage Section 42. During my work with Boeing I had the interesting and challenging opportunity to lead an engineering team from distance, i.e, based in Vitoria I was leading a team of 4 engineers working at Boeing facilities in Seattle, with the added challenge of the 9 hour mismatch due to different time zones (I was finishing my working day when they were starting theirs).

With the broader experience in different projects, my exposure to different cultures and multicultural teams, different organizations, methodologies and techniques, my experience and know-how kept increasing, contributing to my growth both as an individual and as an engineer.

In 2008 I went to work for Bombardier Aerospace in Montreal-Canada, for what I can only describe as the best experience in my life. There I consolidated myself as an experienced senior stress engineer, with my work recognized, and the level of responsibilities increase. I worked as a team leader, coordinating and administrating small teams in Bombardier's fully new aircraft, the C-Series. I was involved in several composite structures such as the Center Wing Box, Keel Beam, Wing to Body Fairing and Tailcone.

I was responsible for final sign-off of all stress-related activities, technical leadership and approval for team members, representing the stress function at design reviews and approving design solutions for structural integrity.

After 10 years abroad, working in cutting edge programs for major aircraft manufacturers such as Airbus, Boeing, Bombardier, Dassault, etc., I was invited to join Ceiiia (Maia-Portugal) and be part of building the Aeronautical Unit, leading the Structural Analysis department and coaching young engineers.

Since November 2012 I am working at Ceiiia, helping to create an aeronautical cluster in Portugal, teaching young engineers, and consolidating a strong Design Office that allows Portugal to keep participating in international programs in the Aerospace industry.

Resumo

Após conclusão da minha licenciatura em engenharia mecânica em 2000, e depois de uma breve experiência na área de automação e pneumática, comecei a trabalhar na indústria aeronáutica como Stress Engineer.

Tive a oportunidade fazer parte de uma empresa extraordinária, Ogma (Alverca-Portugal), que me deu a oportunidade de aprender e aperfeiçoar o meu conhecimento e experiência em stress analysis. Fui enviado para a Airbus (Madrid-Espanha) para um período de formação de 6 meses, formação esta em áreas tão específicas como análise estrutural em estruturas aeronáuticas de materiais compósitos e metálicos, comprovação de resistência, análise de fadiga, FEM, e diferentes tipos de ferramentas e técnicas de validação estrutural, com vários engenheiros Sênior da Airbus.

Ao abrigo de um acordo de colaboração entre a Airbus e a Ogma, esta formação foi complementada com 6 meses a trabalhar na Airbus, integrado na sua equipa de engenharia. As minhas responsabilidades eram: actividades da fase de desenho conceptual do Elevator do Airbus A400M, dimensionamento de peças de compósito, requisitos estruturais, análise estrutural e FEM.

Depois do cancelamento do projecto em que eu estava a trabalhar, e de me aperceber da falta de projectos na área de análise estrutural e desenho de componentes aeronáuticos, decidi sair de Portugal para continuar a minha aprendizagem e continuar a ganhar experiência. Isto só poderia ser feito participando em projectos inovadores e na vanguarda da tecnologia, projectos estes em empresas lideres a nível mundial no sector aeronáutico.

Em 2002 fui para Espanha trabalhar na Aries-Complex (Madrid-Espanha) como stress engineer, nos projectos Falcon 7X Elevator e Airbus A380 Vertical Tail Plane. Depois destes projectos trabalhei na ITD (Madrid-Espanha) no projecto Airbus A380 muffler.

Em 2004 tive a oportunidade de ir para a Bélgica trabalhar na Sonaca (Bruxelas-Bélgica). Fui o responsável das Main Landing Gear Doors do projecto Airbus A400M, do programa de redução de peso das Frames do Embraer 170, e trabalhei ainda no Airbus A380 Nose Upper Shell. Além das minhas responsabilidades de análise estrutural, a desenvolver componentes em material compósito e fazer cálculos de resistência estrutural, também participei na elaboração do manual de reparação estrutural (SRM), o que me permitiu entrar no mundo das reparações estruturais em material compósito.

Após quase 2 anos na Bélgica, regressei a Espanha para trabalhar na Rucker Aerospace (Barcelona-Espanha) e na Aernnova (Vitoria-Espanha). Participei em programas como o Airbus A380 freighter (versão de carga), fuselagem do helicóptero Sikorsky H92, Hawker-Beechcraft Red Wing (desenvolvimento de 3 configurações diferentes de asa para a mesma família de aviões), e a secção 42 da fuselagem do Boeing 747-8 Intercontinental. Durante o meu trabalho com a Boeing tive a oportunidade e o desafio interessante de liderar uma equipa de engenharia à distância, isto é, estando eu em Vitoria (Espanha) estava a liderar uma equipa de 4 engenheiros a trabalhar na fábrica da Boeing em Seattle, com o desafio extra das 9 horas de fuso horário que tínhamos entre nós (quando eu estava a terminar o meu dia de trabalho eles estavam a começar o deles).

Com a experiência em diferentes projectos, o contacto com diferentes culturas e ambientes de trabalho multiculturais, diferentes organizações, metodologias e técnicas de trabalho, a minha experiência e conhecimento continuaram a aumentar, contribuindo para o meu crescimento como pessoa e como engenheiro.

Em 2008 fui trabalhar para a Bombardier Aerospace (Montreal-Canada), naquela que posso descrever como a melhor experiência da minha vida. Na Bombardier consolidei-me como um stress engineer Sénior e com experiência, com o reconhecimento do meu trabalho, e consequente aumento do nível de responsabilidade. Trabalhei como líder de equipa, a coordenar e administrar pequenas equipas no desenvolvimento do novo avião da Bombardier, o C-Series. Estive envolvido no desenvolvimento de vários componentes de material compósito, como o Center Wing Box, Keel Beam, Wing to Body Fairing e o Tailcone.

No projecto C-Series da Bombardier eu era responsável pela assinatura final de todas as actividades relacionadas com Stress analysis, liderança técnica e coordenação das actividades de todos os membros da equipa, representar a função de Stress em design reviews e discussões técnicas com outras disciplinas, e aprovação final de todas as soluções de desenho e integridade estrutural.

Após 10 anos no estrangeiro, a trabalhar em projectos inovadores e na vanguarda da tecnologia com os maiores construtores aeronáuticos mundiais, como a Airbus, Boeing, Bombardier, Dassault, etc., fui convidado para me juntar ao Ceii (Maia-Portugal) e fazer parte da construção da Unidade Aeronáutica, liderando o departamento de análise estrutural e dando formação aos engenheiros mais jovens.

Desde Novembro de 2012 que trabalho no Ceia, ajudando a criar um cluster aeronáutico em Portugal, a ensinar os engenheiros mais jovens, e consolidar um Design Office que permita a Portugal continuar a participar em programas internacionais na indústria aeronáutica.

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1 AEROSPACE COMPOSITE STRUCTURE IMPACT TEST

1.1 INTRODUCTION

This report presents the impact damage resistance test proposal and results analysis for a composite aerospace structure. This structure is a Fairing, with composite skin panels (nomex honeycomb with carbon fiber fabric facings).

Test specimens, representative of the Fairing sandwich panel construction will be used to verify their sensitivity to impact damage by different sources, such as small tools, hail and runway debris. They shall be subjected to impact damage at room temperature and representative impact energy levels.

The impact energy levels associated with the various items considered for foreign object impact on the Fairing are defined in Chapter 1.8).

The strength of the composite structure shall be reliably established, incrementally, through a program of analysis and a series of tests conducted using specimens of varying levels of complexity. Often referred to in industry as the “building block” approach, these tests and analyses at the coupon, element, details, and subcomponent levels can be used to address the issues of variability, environment, structural discontinuity (e.g., joints, cut-outs or other stress risers), damage, manufacturing defects, and design or process-specific details. Typically, testing progresses from simple specimens to more complex elements and details over time. This approach allows the data collected for sufficient analysis correlation and the necessary replicates to quantify variations occurring at the larger structural scales to be economically obtained. The lessons learned from initial tests also help avoid early failures in more complex full scale tests, which are more costly to conduct and often occur later in a certification program schedule.

This report will describe a test campaign at the coupon level.

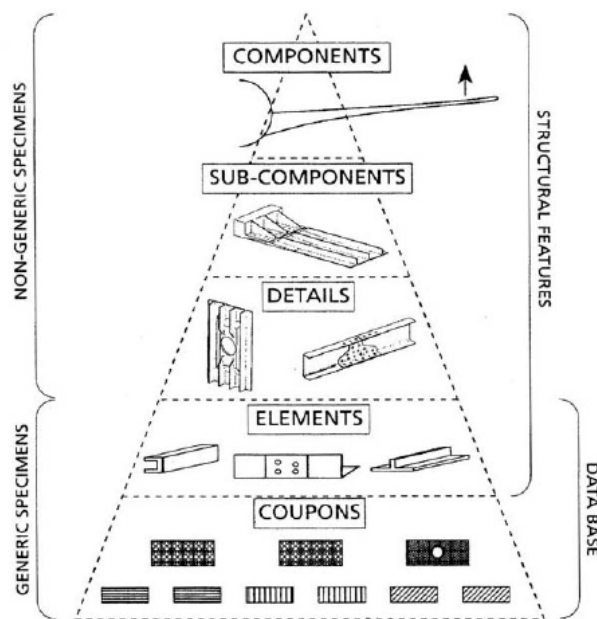


Figure 1 – Schematic diagram of building block tests for a fixed wing

1.2 PURPOSE OF TESTING

1.2.1 GENERAL PURPOSE

The tests defined in this report are part of the Aerospace OEM Fairing design validation testing. The tests shall be used to validate engineering concepts, develop residual strength limitation and test values for specific design features that may not be substantiated through existing OEM allowable programs, as well as determining the Fairing sensitivity to BVID's (Barely Visible Impact Damage). These tests are not considered part of the aircraft certification test program, and are only intended to validate the design for specific durability definitions ensuring product integrity during the life of aircraft.

1.2.2 APPLICABLE REQUIREMENTS

In typical operation, aircrafts are subjected to potential damage from a variety of sources, including maintenance personnel and tools, service equipment, hail and runway debris. Even during initial manufacturing and assembly, parts are subject to dropped tools, bumps/dents during transportation to assembly locations, etc. The aircraft structure must be able to endure a reasonable level of such incidents without requiring costly rework or downtime, therefore this necessitates specific damage resistance quality which is an important design function.

Damage resistance requires robustness, and often requires extra material above that necessary to carry the structural design loads and strength substantiation. It also influences materials choice, lay-up, design details, etc. As a result, a compromise must be found to design a

structure with minimum weight and cost, but that is also able to withstand common impact damages without constant repair to the structure.

In order to establish minimum levels of damage resistance, various requirements for aircraft structure have been identified in the past. The US Air Force requirements are defined by Ref. [1]. This specification defines the type and energy level of impacts that must be sustained without structural impairment, moisture ingress or a requirement for repair. It provides provision for such impacts as dropped tools, hail, and runway debris.

Another reference source is the criteria other large aircraft manufacturer based in Seattle implemented in their new full composite aircraft development program. This requirement can be obtained on internet and is available as public information (Ref. [4]). Furthermore, ASTM D7136 (Ref. [2]) was used as a reference in this document and is available as public information.

For the Fairing design, it was used a mix of Ref. [1], Ref. [2], Ref. [4] and other large aircraft manufacturer requirements (available as public information) to establish damage resistance requirements. These requirements, used as the basis for the test matrix/plan, are summarized in Table 1.

Table 1 - Damage Resistance Requirements

Impact Case	Damage Source	Requirements
1. High Probability Tool Impact	<ul style="list-style-type: none"> • 1.0in diameter solid impactor • low velocity • normal to surface • impact energy of 4ft-lbs ¹ 	<ul style="list-style-type: none"> • no visible damage • no detrimental delamination • no water intrusion
2. Hail (vertical and upward facing horizontal surfaces)	<ul style="list-style-type: none"> • 0.8in diameter • sp. Gr. = 0.9 • 90ft/s • normal to horizontal surfaces • 45 degrees angle to vertical surfaces 	<ul style="list-style-type: none"> • no visible damage • no detrimental delamination • no water intrusion
3. Runway Debris	<ul style="list-style-type: none"> • 0.5in diameter • sp. Gr. = 3.0 • Tangential tire speed ² 	<ul style="list-style-type: none"> • no visible damage • no detrimental delamination • no water intrusion

1. 4ft-lbs = 5.4J

2. KC-390's maximum tangential tire speed = 345ft/s

The condition of no Visible Impact Damage (VID), shall not be confused with a condition of no damage, and can be better referenced as a condition of Barely Visible Impact Damage (BVID).

BVID are small damages which may not be found during heavy maintenance general visual inspections using typical light conditions from a distance of five feet. Structures with BVID are required to resist ultimate design strength and have no detrimental damage growth during design service life, meaning that they are supposed to work as an intact structure.

1.3 ACRONYMS

FEM – Finite Element Model

BVID – Barely Visible Impact Damage

OEM – Original Equipment Manufacturer

M&P – Materials and Processes

DMU - Digital Mock Up

1.4 MANUFACTURING PLAN

For manufacturing plan details see Ref. [7].

1.5 INSPECTION AND WITNESSING

All test specimens shall be inspected under OEM's quality system and properly documented.

Appropriate engineering personnel from OEM shall witness all the tests.

1.6 TEST SPECIMEN DESCRIPTION

The number of specimens to be impacted for each lay-up and energy level is three (one extra specimen shall be manufactured to account for scrapped items). The specimens of the sandwich panel shall be manufactured individually and not cut from one base panel.

The test specimens shall be identical coupons. There shall be a single impact site, located centrally, on each specimen. Grip tabs shall be used at both ends of each test specimen in order to facilitate their installation in the test machine, and also minimize possible damages to the specimen by the clamping fixture (see Figure 6). The test specimens are representative of all sandwich panel configurations used in the Fairing.

1.6.1 LAMINATE AND MATERIAL DESCRIPTION

Table 2 – Test Specimen Materials

Item	Description	Specification
Sandwich Facing	AS4 Carbon/Epoxy Fabric Prepreg	OEM standard
Core	Hexagonal Core	Hexcel HRH-10-1/8-3.0 – ¾"
	Flexcore	Hexcel HRH-10/F50-3.5 – ¾"
Lightning wire	Copper Mesh	OEM standard
Manufacturing Process	177°C Autoclave Cure	OEM standard

The sandwich panels shall be made in two manufacturing steps. In the first step, the core is stabilized using one adhesive film layer on each side, as shown in Figure 2.

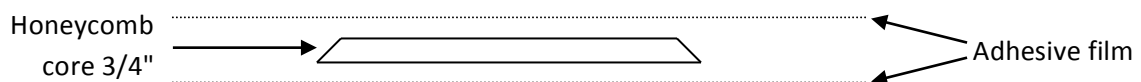


Figure 2 - Stabilized core lay-up

After the core stabilization process, the sandwich panel is laminated following the lay-up of Table 3, in a sketch shown in Figure 3.

Two core options are to be tested. The hexagonal core shall be used in areas with moderate curvature and the flexcore in areas with high curvature. Hexagonal core is used in most Fairing areas, being therefore most representative. All layup configurations will be tested for the hexagonal core, and one layup configuration (the most representative for the fairing, 3plies + core + 2plies) will be tested for the flex core and the results correlated for the other layups.

Four sandwich layup options are being considered for the composite skin design, with 2, 3, and 4 plies on each facing (see Table 4). Besides the carbon facings, all configurations to be tested shall have a lightning wire cloth as external layer (see Figure 3 and Table 3).

Table 3 - Sandwich Panel to be tested.

Ply Number	Material	Orientation
A7	Fabric	± 45
A6	Fabric	0/90
A5	Fabric	0/90
-	Adhesive film	-
-	Stabilized Core (3/4")	-
-	Adhesive film	-
A4	Fabric	± 45
A3	Fabric	0/90
A2	Fabric	0/90
A1	Fabric	± 45
CM	Copper Mesh	-

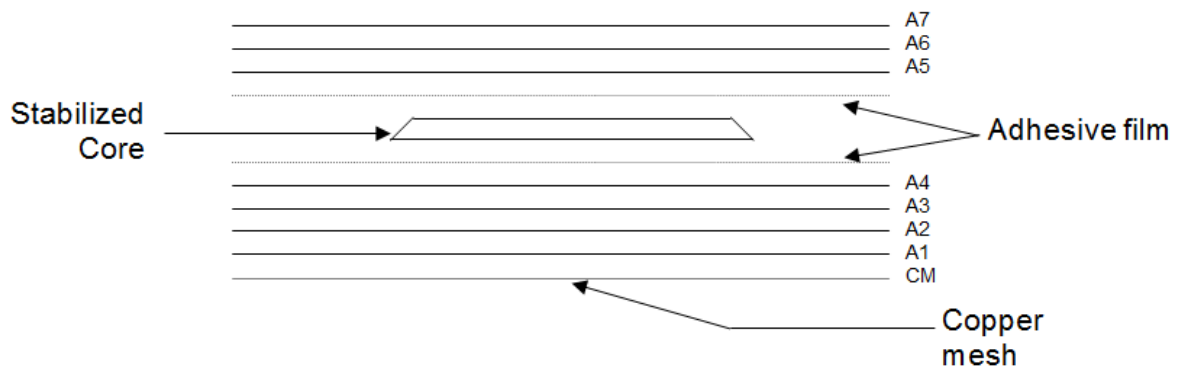


Figure 3 - Sketch of sandwich panel lay-up

Table 4 - Layup of Sandwich Panel to be tested.

Property Number	Number of Plies	Lay Up	Total thickness (mm)
1	5	$\pm 45/90/0/$ HEXA CORE $/90/\pm 45$	20.10
2	6	$\pm 45/90/0/$ HEXA CORE $/0/90/\pm 45$	20.31
3	6	$\pm 45/90/0/ \pm 45/$ HEXA CORE $/90/\pm 45$	20.31
4	7	$\pm 45/90/0/ \pm 45/$ HEXA CORE $/0/90/\pm 45$	20.52
5	5	$\pm 45/90/0/$ FLEXCORE $/90/\pm 45$	20.10

1.6.2 SANDWICH PANEL CONFIGURATION

The sandwich panel impact specimen must be representative of the fairing panels. The impact specimen shall be produced individually, and designed accordingly to the sketch presented in Figure 4.

For the hail impact tests, only the fairing external surface is considered to be impacted by accordingly designed specimen fabrication.

For the runway debris impact tests, the fairing external surface is to be impacted with the exception of one specimen (with a 3plies/Core/3plies configuration), which shall also represent impact to the internal surface in order to check the impact effect without the copper mesh layer (this configuration is representative of the Cargo Bay, where runway debris is likely to occur during landing when the door is fully open).

For the tool impact test, both internal and external surfaces are to be impacted.

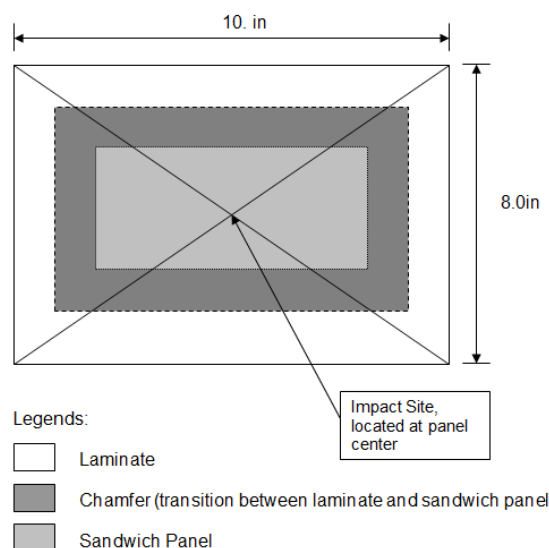


Figure 4 - Sketch of the impact test sandwich panel specimens

The lay-up of the sandwich panel test specimen shall be the same as described in Table 3 and shall be laminated according to Figure 3. The manufacturing process must be the same used to manufacture the correspondent Fairing part.

1.6.3 GENERAL NOTES

- 1 - All specimens must be identified in order to verify and record the results of the tests.
- 2 - All tests shall be conducted at room temperature.

1.7 EQUIPMENT REQUIREMENTS

The equipment must be adequate and certified to perform the procedures requested by this report.

The usual way of performing impact tests in sandwich panels is using a gravity-assisted drop-weight impact-test machine. These machines usually have a data acquisition system, and shall have a rebound-catch mechanism. An example of such a machine is shown in Figure 5.

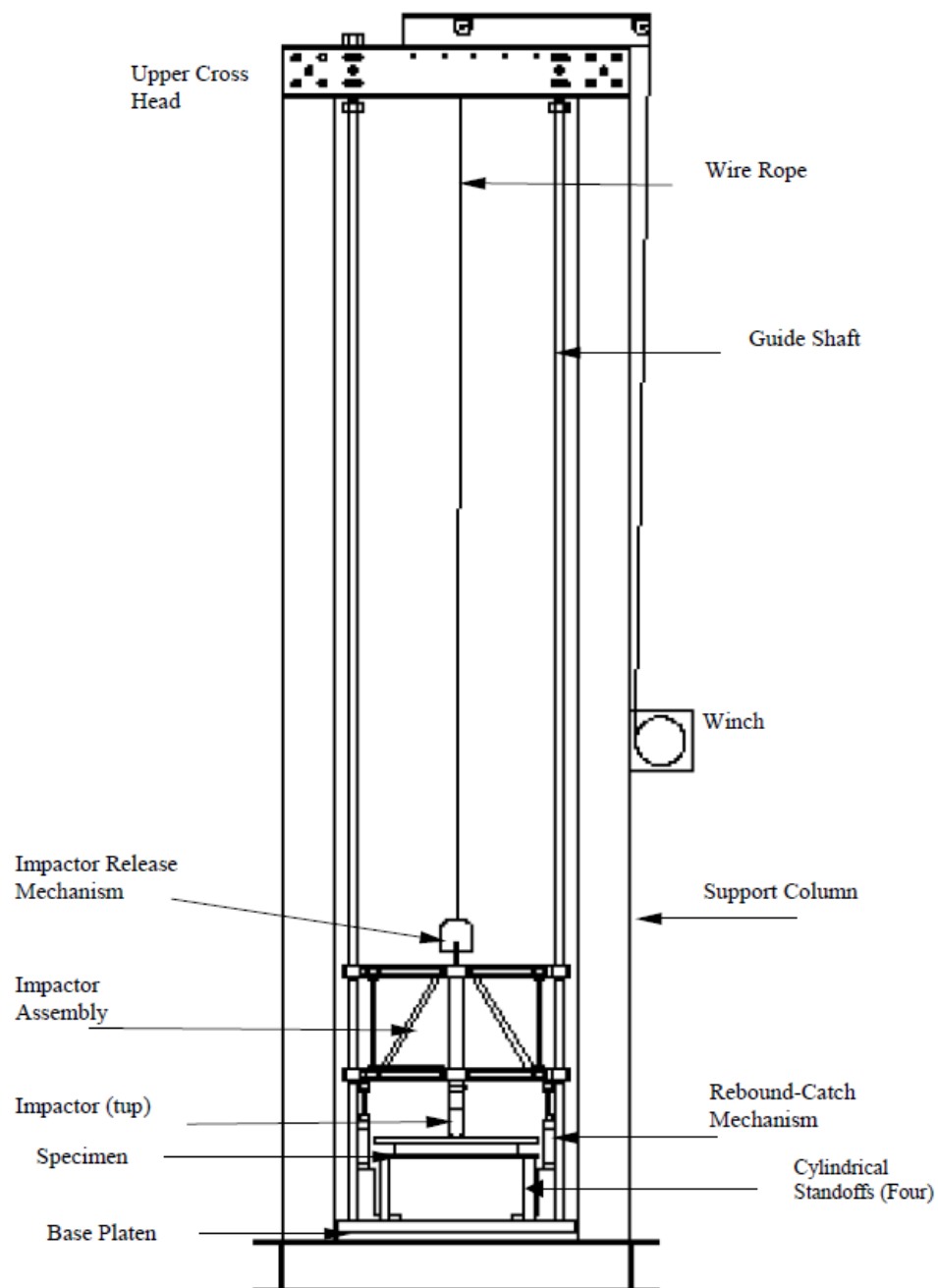


Figure 5 – Example of impact test machine

1.8 TEST MATRIX

Table 5 - Test Matrix

Core height	Laminates	Impactor dia. (in)	Energy level (J)	Impact case	Total panels with scrap factor
0.75"	3+Core +2	1.0"	5.4	Tool	4
	3+Core +3		5.4		4
	4+Core +2		5.4		4
	4+Core +3		5.4		4
	3+Core +2		8.1	Off axis (30 deg.)	4
	3+Core +2	1.0"	5.4	Impact internal surface (Tool)	4
	3+Core +2	0.8"	1.5	Hail Impact external surface	4
	3+Core +3				4
	4+Core +2				4
	4+Core +3				4
	3+Core +2	1.2"	5.0	Off axis (30 deg.)	4
	3+Core +2	1.6"	11.9		4
	3+Core +2	0.5"	17.8	Debris Impact external surface Off axis (45 deg.)	4
	3+Core +3				4
	4+Core +2				4
	4+Core +3				4
	3+Core +3	0.5"	17.8	Impact internal surface (Debris) Off axis (45 deg.)	4
	3+Core +2	1.0"	5.4	Flex Core / Tool	4
		0.8"	1.5	Flex Core / Hail	4
		0.5"	17.8	Flex Core / Debris	4
				Total specimens	80

1.9 TEST PROCEDURE

Once the impact test specimens are ready for testing, the test sequence shall be as follows:

1. Sandwich panels fabrication and preparation;
2. Perform ultra-sound test of the specimen following standards;
3. Perform impact test as described in procedure 8.1;
4. Perform visual inspection in order to verify if there are any visual damages, following standards;
5. Record the presence or absence of visual damage in an appropriate data sheet;
6. Perform ultra-sound test in order to verify if there are any impact-inflicted damage, following the same procedure of item 2;
7. Record the presence or absence of any detectable defects;
8. Record all data in the specific report with photographs of the impacted area and any other essential type of recordings and observations.

1.9.1 PROCEDURE FOR IMPACT TEST

The impact test shall be done using an impactor and fixture as shown in Figure 6. The impactor head shall have a hemispherical steel tip. A guide tube shall be employed to target the impactor above the designated impact region. The fixture shall provide support and locating structure for the impact panel.

The test sequence is:

- 1) Weigh and record the impactor weigh;
- 2) Mark the designated impact location on the center of impact panel, as shown in Figure 4 and Figure 6;
- 3) Place the impact panel in the impact test fixture, as shown in Figure 6;
- 4) Place top clamps on the impact panel and bolt them to the base support structure;
- 5) Align the guide tube above the center of the impact panel. The guide tube installation shall ensure the impact site is within a radius of 5 mm from the designated point.
- 6) Drop the impact head from the appropriate height to generate the required impact energy. Record the height from which the impactor was dropped. The combination of the impactor weight and the drop height (including their respective tolerances) shall generate the required level of energy, with an error of 5% positive.

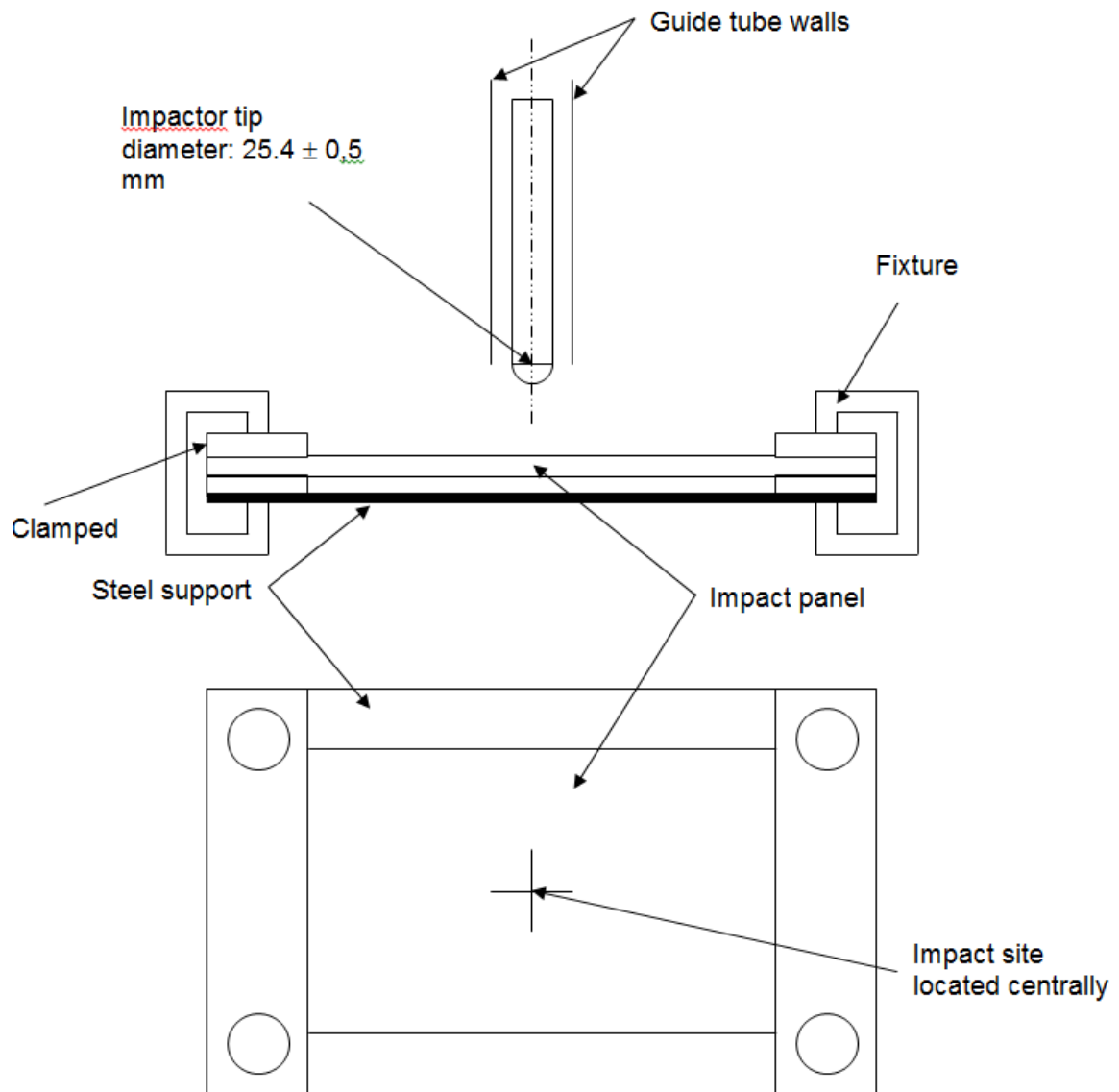


Figure 6 - Impact test fixture and set-up sketch

Notes: 1) Figure not to scale

1.10 TEST REPORT AND RESULTS

1.10.1 DATA SHEET AND TEST REPORT

The test data sheet must include the following information, all included in Ref. [5]:

- 1) Specimen identification → (Ref. [5], Appendix 2)
- 2) Test room temperature → (Ref. [5], Appendix 1.1)
- 3) Test configuration → (Ref. [5], Appendix 2)
- 4) Test loads → (Ref. [5], Appendix 2)
- 5) Failure mode (where applicable) → (Ref. [5], Appendix 2)

The report of test results must include the following information:

- 1) Test data sheet → (Ref. [5], Appendix 1)
- 2) Findings of pre-test inspection → (Ref. [5], Appendix 3)
- 3) Photographs of typical test set-up and test specimen → (Ref. [5], Chapter 3)
- 4) Photographs of any failures - visual or not - if applicable → (Ref. [5], Appendix 2)
- 5) Summary of all manufacturing discrepancies and dispositions
- 6) Documentation of test fixtures or equipment failure (including photographs) → (Ref. [5], Appendix 5)
- 7) Documentation of deviation to test procedures
- 8) Inspection records of non-visible damage area → (Ref. [5], Appendix 4)
- 9) Weight of impactor and height from which it was dropped → (Ref. [5], Appendix 2)
- 10) Copies of conformity inspection tags/reports → (Ref. [5], Appendix 4)
- 11) References for all measuring equipment calibration records → (Ref. [5], Appendix 6)

1.10.2 TEST RESULTS

Results presented herein include the justification for the tests defined in the test matrix (Chapter 1.8), Table 5.

Compliance is shown with the requirements defined in Chapter 1.2.2 Table 1, and the test matrix shown in Table 5.

For legible copies of data presented in sections 1.9.2.1, 1.9.2.2 and 1.9.2.3 see full test results presented in Ref. [5], Appendix 2.

1.10.2.1 TOOL IMPACT TEST RESULTS

Table 6 – Tool Impact Results

Test Config	Surface	TYPE	Off axis	Core	Laminates	Ply stacking Sequences as per ASTM D6507	Nominal Thick. (mm)	Impactor Dia. [in]	Energy Level [J]	Impact Mass [kg]	Calculated Height [mm]	Date	Pass/Fail	Page Cetest rept	Comments
8	External	Tool Impact	0	Hexagonal core, 0.75"	3+2	45/90/0/core/90/45	20.10	1.0	5.4	1.24	445.0	30-07-2013	OK	63	1.0mm
8	External	Tool Impact	0	Hexagonal core, 0.75"	3+2	45/90/0/core/90/45	20.10	1.0	5.4	1.24	445.0	30-07-2013	OK	65	1.0mm
8	External	Tool Impact	0	Hexagonal core, 0.75"	3+2	45/90/0/core/90/45	20.10	1.0	5.4	1.24	445.0	30-07-2013	OK	67	1.0mm
9	External	Tool Impact	0	Hexagonal core, 0.75"	3+3	45/90/0/core/0/90/45	20.31	1.0	5.4	1.24	445.0	30-07-2013	OK	105	1.0mm
9	External	Tool Impact	0	Hexagonal core, 0.75"	3+3	45/90/0/core/0/90/45	20.31	1.0	5.4	1.24	445.0	30-07-2013	OK	107	1.0mm
9	External	Tool Impact	0	Hexagonal core, 0.75"	3+3	45/90/0/core/0/90/45	20.31	1.0	5.4	1.24	445.0	30-07-2013	OK	109	1.0mm
10	External	Tool Impact	0	Hexagonal core, 0.75"	4+2	45/90/0/-45/core/90/45	20.31	1.0	5.4	1.24	445.0	30-07-2013	OK	125	0.1mm
10	External	Tool Impact	0	Hexagonal core, 0.75"	4+2	45/90/0/-45/core/90/45	20.31	1.0	5.4	1.24	445.0	30-07-2013	OK	127	0.1mm
10	External	Tool Impact	0	Hexagonal core, 0.75"	4+2	45/90/0/-45/core/90/45	20.31	1.0	5.4	1.24	445.0	30-07-2013	OK	129	0.4mm
11	External	Tool Impact	0	Hexagonal core, 0.75"	4+3	45/90/0/-45/core/0/90/45	20.52	1.0	5.4	1.24	445.0	30-07-2013	OK	139	0.5mm
11	External	Tool Impact	0	Hexagonal core, 0.75"	4+3	45/90/0/-45/core/0/90/45	20.52	1.0	5.4	1.24	445.0	30-07-2013	OK	141	0.5mm
11	External	Tool Impact	0	Hexagonal core, 0.75"	4+3	45/90/0/-45/core/0/90/45	20.52	1.0	5.4	1.24	445.0	30-07-2013	OK	143	0.5mm
14	External	Tool Impact	30	Hexagonal core, 0.75"	3+2	45/90/0/core/90/45	20.10	1.0	8.1	1.24	667.5	08-08-2013	OK	75	Off axis 30deg, 0mm
14	External	Tool Impact	30	Hexagonal core, 0.75"	3+2	45/90/0/core/90/45	20.10	1.0	8.1	1.24	667.5	08-08-2013	OK	77	Off axis 30deg, 0mm
14	External	Tool Impact	30	Hexagonal core, 0.75"	3+2	45/90/0/core/90/45	20.10	1.0	8.1	1.24	667.5	08-08-2013	OK	79	Off axis 30deg, 0mm
14	External	Tool Impact	30	Hexagonal core, 0.75"	3+2	45/90/0/core/90/45	20.10	1.0	8.1	1.24	667.5	08-08-2013	OK	81	Off axis 30deg, 0mm
13	Internal	Tool Impact	0	Hexagonal core, 0.75"	3+2	+45/90/0/core/90/+45	20.10	1.0	5.4	1.24	445.0	30-07-2013	OK	43	1.9mm
13	Internal	Tool Impact	0	Hexagonal core, 0.75"	3+2	+45/90/0/core/90/+45	20.10	1.0	5.4	1.24	445.0	30-07-2013	OK	45	1.9mm
13	Internal	Tool Impact	0	Hexagonal core, 0.75"	3+2	+45/90/0/core/90/+45	20.10	1.0	5.4	1.24	445.0	30-07-2013	OK	47	1.9mm

1.10.2.2 HAIL IMPACT TEST RESULTS

Table 7 – Hail Impact Results

Test Config	Surface	TYPE	Off axis	Core	Laminates	Ply stacking Sequences as per ASTM D6507	Nominal Thick. (mm)	Impactor Dia. [in]	Energy Level [J]	Impact Mass [kg]	Calculated Height [mm]	Date	Pass/Fail	Page Cetest rept	Comments
17	External	Hail Impact	0	Hexagonal core, 0.75"	3+3	+45/90/0/core/0/90/+45	20.31	0.8	1.5	1.21	126.8	23-07-2013	OK	97	0.0mm
17	External	Hail Impact	0	Hexagonal core, 0.75"	3+3	+45/90/0/core/0/90/+45	20.31	0.8	1.5	1.21	126.8	23-07-2013	OK	99	0.0mm
17	External	Hail Impact	0	Hexagonal core, 0.75"	3+3	+45/90/0/core/0/90/+45	20.31	0.8	1.5	1.21	126.8	23-07-2013	OK	101	0.5mm, Impact application mistake, Energy 2.5 J
17	External	Hail Impact	0	Hexagonal core, 0.75"	3+3	+45/90/0/core/0/90/+45	20.31	0.8	1.5	1.21	126.8	23-07-2013	OK	103	0.0mm
18	External	Hail Impact	0	Hexagonal core, 0.75"	3+2	45/90/0/core/90/45	20.10	1.2	5	1.30	391.8	23-07-2013	OK	51	ok; 0.0mm
18	External	Hail Impact	0	Hexagonal core, 0.75"	3+2	45/90/0/core/90/45	20.10	1.2	5	1.30	391.8	23-07-2013	OK	53	ok; 0.0mm
18	External	Hail Impact	0	Hexagonal core, 0.75"	3+2	45/90/0/core/90/45	20.10	1.2	14	1.30	1096.9	23-07-2013	OK	55	Impactor Breaks (at thread location);
16	External	Hail Impact	30	Hexagonal core, 0.75"	3+2	+45/90/0/core/90/+45	20.10	1.6	11.9	2.41	503.1	07-08-2013	OK	25	Off axis 30deg, 0.3mm
16	External	Hail Impact	30	Hexagonal core, 0.75"	3+2	+45/90/0/core/90/+45	20.10	1.6	11.9	2.41	503.1	07-08-2013	OK	33	Off axis 30deg, 0.2mm
16	External	Hail Impact	30	Hexagonal core, 0.75"	3+2	+45/90/0/core/90/+45	20.10	1.6	11.9	2.41	503.1	07-08-2013	OK	41	Off axis 30deg, 0.2mm
16	External	Hail Impact	30	Hexagonal core, 0.75"	3+2	+45/90/0/core/90/+45	20.10	1.6	11.9	2.41	503.1	07-08-2013	OK	49	Off axis 30deg, 0.2mm

Some configurations defined in the Test Matrix (for example 3+2 with an energy level of 1.5J) were not tested as they are justified by configuration #18, 3+2 plies with energy level of 5.0J (and

one specimen tested with 14.0J, to push the test to the limit), and configuration #16, 3+2 plies with energy level of 11.9J.

1.10.2.3 RUNWAY DEBRIS IMPACT TEST RESULTS

Table 8 – Runway Debris Impact Results

Test Confi	Surface	TYPE	Off axis	Core	Laminates	Ply stacking Sequences as per ASTM D6507	Nominal Thick. (mm)	Impactor Dia. (in)	Energy Level (J)	Impact Mass (kg)	Calculated Height (mm)	Date	Pass/Fail	Page of test report	Comments
21	External	Runway Debris	45	Hexagonal core, 0.75"	3+2	45/90/0/core/90/45	20.10	0.5	17.8	2.16	838.9	23-07-2013	OK	83	0.0mm
21	External	Runway Debris	45	Hexagonal core, 0.75"	3+2	45/90/0/core/90/45	20.10	0.5	17.8	2.16	838.9	23-07-2013	OK	85	0.0mm; Impactor Breaks
21	External	Runway Debris	45	Hexagonal core, 0.75"	3+2	45/90/0/core/90/45	20.10	0.5	17.8	2.16	838.9	23-07-2013	OK	87	0.0mm; Impactor Breaks
20	Internal	Runway Debris	45	Hexagonal core, 0.75"	3+3	45/90/0/core/0/90/45	20.31	0.5	17.8	2.16	839.6	30-07-2013	OK	111	Impact Internal surface; off axis 45deg. 0mm
20	Internal	Runway Debris	45	Hexagonal core, 0.75"	3+3	45/90/0/core/0/90/45	20.31	0.5	17.8	2.16	839.6	30-07-2013	OK	113	Impact Internal surface; off axis 45deg. 0mm
20	Internal	Runway Debris	45	Hexagonal core, 0.75"	3+3	45/90/0/core/0/90/45	20.31	0.5	17.8	2.16	839.6	30-07-2013	OK	115	Impact Internal surface; off axis 45deg. 0mm

Some configurations defined in the Test Matrix (for example 3+3, 4+2 and 4+3 plies with an energy level of 17.8J) were not tested as they are justified by configuration 21, 3+2 plies with energy level of 17.8J.

1.11 REQUIREMENTS COMPLIANCE DEMONSTRATION

Correlation between the test results and the test proposal requirements is shown in Table 9.

Table 9 – Compliance Matrix

REQUIREMENT			REQUIREMENT COMPLIANCE DEMONSTRATION		
Documents	Requirement Description	Ref.	Documents	Requirement Compliance Demonstration Description	Ref.
Fairing Impact Test Proposal "Aerospace Composite Structure Impact Test"; Test Matrix "Fairing_Test_Matrix_Rev-x15"	Aerospace composite structure, when subjected to potential damage from a variety of sources, including tools, hail and runway debris, shall resist ultimate load and have no detrimental damage growth during design service life, meaning that they are supposed to work as an intact structure.	Page 5, Table 1; Page 11, Table 5;	Testing Laboratory Test Report:	Compliance with the requirements is show by the results from test configurations:	Page 63, 65, 67; 105, 107, 109; 125, 127, 129; 139, 141, 143; 75, 77, 79, 81; 43, 45, 47
	BVID's are small damages which may not be found during heavy maintenance general visual inspections using typical lighting conditions from a distance of five feet.	Page 12, Table 6;		Hail Impact: #17, 18 and 16	Page 97, 99, 101, 103 51, 53, 55; 25, 33, 41, 49
	Built specimens as described in Chapter 5 from Test Proposal, as per test matrix, and also according to OEM M&P standard XXX.	Page 6		Runway Debris Impact: #21 and 20	Page 83, 85, 87; 111, 113, 115
	Test according to Fairing Impact Test Proposal, following procedure defined in chapter 8.	Page 13		Specimens built according to test procedure chapter 3; Specimens quality ensured and demonstrated by Ultrasonic inspection, as shown in Test Report Appendix 3 and 4	Pages 7-8 Page 159 Page 164
			Testing Laboratory Test Procedure	Tests executed as defined in Fairing Test Proposal. It is shown that impactor diameter and mass, energy levels and drop height are applied as per Test Proposal and Test Matrix.	Pages 15, 16 Pages 19-151
				Test Report Appendix 1 and 2	Pages 11-13

1.11.1 FAIRING REPRESENTATIVE LAYUP CONFIGURATIONS

- **3plies+Core+2plies:** compliance shown. The tests performed showed no sign of BVID as the subsequent to testing inspection confirmed. Result of inspections and photographs of the tested specimen are presented under Ref. [5], configurations 8, 13, 14, 16, 18 and 21.

This is the thinnest layup in the entire Fairing.

- **3plies+Core+3plies:** compliance shown. The tests performed showed no sign of BVID as the subsequent to testing inspection confirmed. Result of inspections and photographs of the tested specimen are presented under Ref. [5], configurations 9, 17 and 20.

This configuration is especially representative of the Main Landing Gear Bay.

- **Thicker laminates:** For example Doors configuration with **6plies+Core+6plies**, was not tested and is justified by the thinner configurations (3+2 and/or 3+3)

1.11.2 EXTERNAL/INTERNAL IMPACT SURFACES

Compliance is shown for impacts on both external (more representative) and internal surfaces. The tests performed showed no sign of BVID as the subsequent to testing inspection confirmed.

The majority of configurations were tested with impacts on the external surface, more representative of the Fairing.

One configuration was tested with impacts on the internal surface, simulating tool impact (configuration 13, Ref. [5]). Another configuration was tested with impacts on the internal surface, simulating runway debris impact (configuration 20, Ref. [5]), which is representative of the Cargo Bay, where runway debris is likely to occur during landing when the door is fully open (3plies+Core+3plies).

1.11.3 IMPACT ANGLES

Impacts were performed normal to the surface (90degrees), and also at different impact angles (45degrees and 30 degrees, designated off axis tests). Compliance is shown in all cases.

The tests performed showed no sign of BVID as the subsequent to testing inspection confirmed. Result of inspections and photographs of the tested specimen are presented under Ref. [5], configurations 14, 16, 20 and 21.

1.11.4 HEXAGONAL AND FLEX CORE

Hexagonal core is used in most Fairing sandwich panels, being therefore most representative. All layup configurations were tested for the hexagonal core, and one layup configuration (the most representative for the fairing, 3plies + core + 2plies) was tested for the flex core and the results correlated for the other layups.

Comparing results with Hexa and Flex core, results are slightly better with Flex core.

The Flex core being more flexible and with lower stiffness, absorbs the impact energy better. For this reason it was decided not to test more Flexcore specimens, as results would be better than Hexacore, therefore it is already justified by Hexa specimens results.

Substantiation for this effect can be seen in Ref. [5], with results for configuration 15 (Flex), pages 145 thru 152, and configuration 1 (Hexa), pages 19 thru 24.

1.12 CONCLUSIONS

The test results for damages by sources such as small tools, hail, and runway debris show compliance with the requirements defined in this report (see Table 9).

Test specimens, representative of the Fairing sandwich panel construction, show damage resistance robustness, and are able to withstand representative impact energy levels with BVID.

1.13 REFERENCES

- [1] Department of Defense – Joint Service Specification Guide – Aircraft Structures – JSSG-2006 – 30 October 1998
- [2] ASTM D7136 - Standard Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer Matrix Composite to a Drop-Weight Impact Event
- [3] Test Matrix ("*Fairing_Test_Matrix_Rev.xls*")
- [4] Boeing Composite Airframe Damage Tolerance and Service Experience – Boeing Commercial Airplanes 787 Program - a presentation by Allen J. Fawcett and Gary D. Oakes publicly available at <http://www.niar.wichita.edu/>
- [5] *Testing Laboratory* Test Report
- [6] *Testing Laboratory* Test Procedure
- [7] *Engineering company* Production Manual

2 CURRICULUM VITAE

Experienced professional with over 14 years' experience in Aerospace sector in stress analysis.

Experience abroad in different countries.

Strong communication and interpersonal skills, and a pro-active approach to problem solving.

Experience as a team leader, coordinating and administrating small teams (10 to 15 people).

Coordination of projects, meetings and negotiations with clients and suppliers.

PERSONAL INFORMATION

Name	LOPES MARÇAL, CAMILO
Nationality	Portuguese
Date of birth	20th, September, 1977
Telephone	934316942
Email	camilo.marcal@gmail.com

WORK EXPERIENCE

- | | |
|--|--|
| • Dates (from – to) | Since November 2012 |
| • Name and address of employer | CEIIA, Maia, Portugal |
| • Type of business or sector | Aerospace |
| • Occupation or position held | Stress Leader in the Embraer KC390 project. |
| • Main activities and responsibilities | <p>Elevator and Sponson project:</p> <p>Stress analysis of composite parts; stress analysis of metallic parts; detailed FEM using Patran/Nastran; stress reports.</p> <p>Conceptual design ensuring the structural integrity of the sub assembly; static stress calculations to assess design solutions and ensure design solutions are structurally optimized.</p> <p>Final sign-off of all stress-related activities; technical leadership and approval for team members; project management tasks.</p> <p>Representing the stress function at design reviews and approving design solutions for structural integrity.</p> |
| • Dates (from – to) | Since August 2008 |
| • Name and address of employer | Bombardier Aerospace, Montreal, Canada |
| • Type of business or sector | Aerospace |
| • Occupation or position held | Stress Leader in the Bombardier C-Series project. |

- Main activities and responsibilities

Bombardier C-Series Center Wing Box, Keel Beam, Wing to Body Fairing and Tailcone: Stress analysis of composite parts; stress analysis of metallic parts; detailed FEM using Patran/Nastran; stress reports.

Conceptual design ensuring the structural integrity of the sub assembly; static stress calculations to assess design solutions and ensure design solutions are structurally optimized.

Final sign-off of all stress-related activities; technical leadership and approval for team members; project management tasks.

Representing the stress function at design reviews and approving design solutions for structural integrity.

- Dates (from – to)

Since November 2006
 - Name and address of employer

[Aernnova Engineering, Vitoria, Spain](#)
 - Type of business or sector

Aerospace
 - Occupation or position held

Stress Engineer on Sikorsky H92, Hawker-Beechcraft Red Wing, Emb145, Emb170 and Boeing 747-8 Intercontinental projects.
- Main activities and responsibilities

Sikorsky H92 fuselage, Hawker-Beechcraft “Red Wing” Wingbox and control surfaces, Emb145XR Wing, Boeing 747-8 Intercontinental Fuselage Section 42:

Stress analysis of composite parts; hand calcs of honeycomb panels and solid laminate panels; stress analysis of metallic parts; computer calcs using Gamesa stress software; computer calcs using Sikorsky stress software; computer calcs using Boeing stress software; detailed FEM using Patran/Nastran; hand calcs; stress reports.

- Dates (from – to)

From January until October 2006
 - Name and address of employer

[Rucker Aerospace, Barcelona, Spain](#)
 - Type of business or sector

Aerospace
 - Occupation or position held

Stress Engineer on Airbus A380F project
- Main activities and responsibilities

A380F Main Landing Gear Doors:

Stress analysis of metallic parts; computer calcs using Airbus stress software; detailed FEM using Patran/Nastran; hand calcs; stress reports.

- Dates (from – to)

From July 2004 until December 2005
 - Name and address of employer

[Sonaca SA, Brussels, Belgium](#)
 - Type of business or sector

Aerospace
 - Occupation or position held

Stress Engineer on A400M, Airbus A380 and Emb170 projects
- Main activities and responsibilities

A400M Main Landing Gear Doors, Emb170 Frames weight reduction, A380 Nose Upper Shell:

Stress analysis of composite parts (skins, ribs, omega stiffeners); hand calcs of solid laminate panels; stress analysis of metallic parts; computer calcs using Airbus stress software; computer calcs using Sonaca stress software; detailed FEM using Patran/Nastran; detailed FEM using Samcef; hand calcs; stress reports; composite trade-off studies bringing up new design solutions; flutter analysis; mass estimation; interface loads; structural repair manual (SRM).

- Dates (from – to)

From February 2004 until July 2004
 - Name and address of employer

ITD, Madrid - Spain
 - Type of business or sector

Aerospace
 - Occupation or position held

Stress Engineer on Airbus A380 project

- Main activities and responsibilities
 - A380 Muffler:
Stress analysis of composite parts; hand calcs of solid laminate panels; stress analysis of metallic parts; computer calcs using Airbus stress software; detailed FEM using Patran/Nastran; stress reports.

- Dates (from – to)
 - From December 2002 until January 2004
 - Name and address of employer
 - [Aries Complex, Madrid, Spain](#)
 - Type of business or sector
 - Aerospace
 - Occupation or position held
 - Stress Engineer on Falcon 7X and Airbus A380 projects
 - Main activities and responsibilities
 - Falcon 7X Elevator, A380 VTP ribs:
Stress analysis of composite parts (spars, skins, ribs, leading edge); hand calcs of honeycomb and solid laminate panels; stress analysis of metallic parts; computer calcs using Airbus/CASA stress software; detailed FEM using Patran/Nastran; hand calcs; stress reports; composite trade-off studies bringing up new design solutions; flutter analysis; research and development of defects, impacts, structural repairs and extensometers on spars, ribs and skins for HTP full-scale test; specific requirement processes for spars and ribs.

- Dates (from – to)
 - From April 2001 until November 2002
 - Name and address of employer
 - [OGMA SA, Lisbon, Portugal](#)
 - Type of business or sector
 - Aerospace
 - Occupation or position held
 - Stress Engineer on A400M project
 - Main activities and responsibilities
 - A400M Elevator and Wing to Fuselage Fairing:
Stress analysis of composite parts (spars, skins, ribs, leading edge, fairings); hand calcs of solid laminate parts; stress analysis of metallic parts; computer calcs using Airbus/CASA stress software; detailed FEM using Patran/Nastran; hand calcs; stress reports; composite trade-off studies bringing up new design solutions.

- Dates (from – to)
 - From October 2000 until April 2001
 - Name and address of employer
 - Rexroth Mecman, Lisbon - Portugal
 - Type of business or sector
 - Hydraulic and pneumatic systems
 - Occupation or position held
 - Mechanical Engineer
 - Main activities and responsibilities
 - Industrial automation; hydraulics; pneumatics.

EDUCATION AND TRAINING

- Dates (from – to)
 - From 6th May until 10th May 2002
 - Name and type of organisation providing education and training
 - MSC Software Madrid
 - Principal subjects/occupational skills covered
 - MSC.Nastran / MSC. Patran seminar: Linear Static, Normal Modes and Buckling Analysis using MSC. Nastran and MSC. Patran (NAS120)**
 - Title of qualification awarded
 - NAS 120

<ul style="list-style-type: none"> • Dates (from – to) • Name and type of organisation providing education and training • Principal subjects/occupational skills covered • Title of qualification awarded 	<p>From 1st October until 25th October 2001</p> <p>OGMA Indústria Aeronáutica de Portugal</p> <p>Intensive course in Reliability (32 hours)</p>
<ul style="list-style-type: none"> • Dates (from – to) • Name and type of organisation providing education and training • Principal subjects/occupational skills covered • Title of qualification awarded 	<p>From 8th October until 9th October 2001</p> <p>OGMA Indústria Aeronáutica de Portugal</p> <p>Intensive course in Statistics (15 hours)</p>
<ul style="list-style-type: none"> • Dates (from – to) • Name and type of organisation providing education and training • Principal subjects/occupational skills covered • Title of qualification awarded 	<p>From 25th July until 31st July 2001</p> <p>OGMA Indústria Aeronáutica de Portugal</p> <p>Intensive course in Quality Management (35 hours)</p>
<ul style="list-style-type: none"> • Dates (from – to) • Name and type of organisation providing education and training • Principal subjects/occupational skills covered • Title of qualification awarded 	<p>From 27th July until 8th September 2000</p> <p>University of Miskolc (Hungary), Department of Materials Handling and Logistics</p> <p>Practical training in Logistics and “Just in Time”</p>
<ul style="list-style-type: none"> • Dates (from – to) • Name and type of organisation providing education and training • Principal subjects/occupational skills covered • Title of qualification awarded • Level in national classification 	<p>From 1995 to 2000</p> <p>Faculdade de Ciências e Tecnologia from Universidade Nova de Lisboa, Portugal</p> <p>Degree in Mechanical Engineering</p> <p>Degree in Mechanical Engineering</p> <p>Merit award for being the 2nd best mechanical engineering student of 2000</p>

PERSONAL SKILLS AND COMPETENCES

MOTHER TONGUE **Portuguese**

OTHER LANGUAGES

English

- Reading skills Excellent
- Writing skills Excellent
- Verbal skills Excellent

Spanish

- Reading skills Excellent
- Writing skills Excellent
- Verbal skills Excellent

French

- Reading skills Good
- Writing skills Basic
- Verbal skills Good

ORGANISATIONAL SKILLS
AND COMPETENCES

Strong communication and interpersonal skills, and a pro-active approach to problem solving; experience as a team leader, coordinating and administrating small teams (5 to 10 people); coordination of projects, meetings and negotiations with clients and suppliers.

TECHNICAL SKILLS
AND COMPETENCES

Windows XP, MsOffice, Unix, Acad, Solid Works, CATIA v4 and v5, the F.E.M. codes Cosmos, Ansys, Femap, Samcef and PATRAN/NASTRAN, as well the programming languages Basic, Pascal, C++ and Assembly

ADDITIONAL INFORMATION

Mr. Patrick Beaudry – Cseries Manager – Bombardier Aerospace
Mr. Harry Black –Stress Section Chief, Aernnova
Mr. Dean A. Cox – Airbus Manager Programs , Airbus North America – Mobile
Mr. Nicola Van Hille – A400M Head of Stress and Project Manager – Sonaca Belgium